3.2. Ecology and Environment of Mangrove Ecosystems

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The mangrove environment has some special physicochemical characteristics of salinity, tidal currents, winds, high temperatures, and muddy anaerobic soil. Plants of the environment are able to adapt to themselves to practically all types of adverse conditions except perhaps frost, and hence they are distributed mostly in the tropical regions. Probably there are no other groups of plants with such highly developed adaptations to extreme conditions. Mangroves occur in low-lying, broad coastal plains where the topographic gradients are small and the tidal amplitude large. Repeatedly getting flooded, but well-drained soil supports a rich growth of mangrove plants. They normally grow poorly in stagnant waters and have luxuriant growth in the alluvial soil substrates with fine-textured loose mud or silt, rich in humus and sulphides. They can also be found in substrates other than muddy soil such as coastal reefs and oceanic islands. In such areas, the mangrove plants grow on peat, which is derived from decayed vegetation. They find it difficult to colonize the coastal zone with waves of high energy and hence they normally establish themselves in sheltered shorelines (Kathiresan & Bingham, 2001).

Types of Coastal Settings

Mangroves get tightly bound to the coastal environments in which they occur. Not only are they influenced by chemical and physical conditions of their environment, but they usually help to create those conditions by themselves. They are found in a variety of tropical coastal settings like the deltas, estuarine areas with their own deltas, lagoons, and fringes of the coral reefs (Fig. 1).
There are normally six functional types of mangrove forests as shown in Fig. 2, namely, fringe, riverine, basin, overwash, scrub (dwarf) and hommock forests. The last three types are the modified forms of the first three types. The six types can be summarized as follows:

1. **Overwash mangrove forests:** These are small mangrove islands, frequently formed by tidal washings.

2. **Fringing mangrove forests:** These occur along the borders of protected shorelines and islands, influenced by daily tidal range. They are sensitive to erosion and long exposure to purely marine conditions with turbulent waves, and tides.

3. **Riverine mangrove forests:** These are luxuriant patches of mangroves existing along rivers and creeks, which get flooded daily by the tides. Such forests are influenced with the incursion of large amount of freshwater with fluvial nutrients and thus making the system highly productive with trees growing taller.

4. **Basin mangrove forests:** These are stunted mangroves located along the interior side of the swamps and in drainage depressions. Their positioning channels the terrestrial runoff to move towards the coast with a slow velocity of water flow.

5. **Hammock mangrove forests:** These are similar to the basin type except that they occur in more elevated sites than the four types given above.
6. **Scrub mangrove forests**: These form dwarf mangrove settings along flat coastal fringes.

![Diagram of six types of mangrove forests](image)

Fig. 2. Six types of mangrove forests of common occurrence  
(From Lugo & Snedaker, 1974; Woodroffe, 1992)

The type of classification noted above has limitations in providing information on the physical processes that take place in all the types of forests. Therefore, a new classification has been suggested. This includes river-dominated, tide-dominated and interior mangrove forests (that have less influence of river/or tides). The modified classification has been shown diagrammatically in Fig. 3.
Fig. 3. Relationship between the types of mangrove forests and two dominant physical processes (Tide and river). Strong outwelling is a characteristics of river dominated mangroves. Bidirectional flux is a unique feature of tide dominated mangroves. Mangroves located in the interior typically form sinks for sediment nutrients (From Woodroffe, 1992).

Based on the substrate, tidal range and sedimentation, six more broad classes of mangrove settings have been given as follows by Thom (1982) and Galloway (1982):

1. Large deltaic systems (occurring in low tidal range, very fine allochthonous sediments) (e.g. mangroves of Borneo, Sundarbans)
2. Tidal plains (where alluvial sediments are reworked by the tides; and there is the presence of large mudflats for the growth of mangroves)
3. Composite plains; under the influence of both tidal and alluvial conditions (e.g. lagoons formed behind wave-built barriers where mangroves grow)
4. Fringing barriers with lagoons (high wave energy conditions with autochthonous sediments of fine sand and mud) (e.g. mangroves of the Philippines),
5. Drowned bedrock valleys (e.g. mangroves of Northern Vietnam or Eastern Malaysia)
6. Coral coasts (mangroves growing at the bottom of coral sand or in platform reefs) (e.g. mangroves of India, Indonesia and Singapore)

Most of the types of mangrove forests noted above get frequently affected by rapid changes in coastal geomorphology. Many ecological factors strongly influence the well-being of mangroves and these include geographical latitudes, wave action, rainfall, freshwater runoff, erosion/sedimentation rates, aridity, salinity, nutrient inputs, and soil quality (Kjerfve et al., 1999). Primary productivity and biomass of mangroves normally decrease with increasing latitudes (Clough, 1992; Fig.4).

Fig.4. Relationship between latitudes and mangrove biomass (a) and or mangrove litterfall ($r^2 = 0.1$) (From Saenger and Snedaker, 1993)
Ecological characteristics

Tidal gradient

In general, coasts with a greater tidal range can help in colonization of extensive mangrove forests. A greater tidal range increases the intertidal area and depending on the slope of the substrate, which if smooth encourages the growth of mangroves. The topography of a mangrove swamp is normally smooth and flat. However, any rise or fall of the land can greatly influence the direction and rate of flow of the water in the system, which changes the colonization of mangroves.

Many species of mangroves respond differently to different tidal regimes. For example, in the Sundarban area of India, a mangrove forest that experiences total diurnal inundation is dominated by *Avicennia marina* and *A. alba* while *Excoecaria agallocha*, *Ceriops dacandra* and *Acanthus ilicifolius* get dominated at sites that are not completely inundated (Saha & Choudhury, 1995). *Nypa fruticans* also seems to prefer sites with low level of tidal inundation (Siddiqi, 1995). If diversity is high, mangroves get extremely variable in their location (Bunt, 1996). Their “zones” may be obscured by a broad overlap in species distribution or they may simply remain absent in some mangals.

Temperature

Mangroves attain climax growth only under tropical conditions where atmospheric temperature in the coldest months is greater than 20°C and the seasonal fluctuation does not exceed 5°C. Mangroves have been reported to grow in latitudes where the average sea surface temperature is 24°C. Any further rise in temperature may lead to spreading of only some species in to higher latitudes, provided that the direction of ocean currents facilitates the dispersal of their seeds. However, very high temperatures are not favourable as leaves of mangroves are sensitive to temperature and their photosynthetic capacity gets reduced, falling to zero at leaf temperatures of 38-40°C, as against the optimum leaf temperature for photosynthesis which is 28-32°C (Clough et al., 1982; Andrews et al., 1984). A small increase in temperature may not adversely affect the flowering, but may change their reproductive cycle and thus may alter the duration between flowering and the fall of ripe seeds.

Global warming may lead to sea level rise and as a consequence of that, mangroves may shift more landward. However, in many parts of the world, mangroves are unlikely to migrate landward because of
human settlement at the landward boundary and the width of the mangrove forests is likely to decrease under the rise in sea level (Kjerfve & Macintosh, 1997). The effects of sea level rise on any mangrove habitat will be influenced by local conditions such as the wetland type, geomorphic setting, and human activities in the wetland. It is predicted that the sea level rise may range from 45 to 65 cm /100 year (Stewart et al., 1990). However, mangroves could survive a rise rate of 8-9 cm/100 year and hence the predicted faster rates could seriously threaten mangrove ecosystems (Ellison & Stoddart, 1991). This view was challenged by Snedaker et al. (1994) who cited historical records showing mangrove expansion under relative sea level changes nearly twice as great. Tan and Zhang (1997) conclude that, given the predicted rates of estimate, the sea level rise poses no serious threat to most mangrove forests in China.

**Salinity**

Salinity plays a vital role in the distribution of species, their productivity and growth of mangrove forests (Twilley & Chen, 1998). Changes in salinity are normally controlled by climate, hydrology, rainfall, topography and tidal flooding.

Mangroves generally tolerate higher salinity than do non-mangrove plants, but tolerance also varies among the mangroves. For example, *Rhizophora mucronata* seedlings do better in salinities of 30 %0, but *R. apiculata* do better at 15 %0 (Kathiresan & Thangam, 1990; Kathiresan et al., 1996b). *Sonneratia alba* grows in waters between 2 %0 and 18 %0, but *S. lanceolata* only tolerates salinities up to 2 %0 (Ball and Pidsley, 1995).

In general, mangrove vegetation is more luxuriant in lower salinities (Kathiresan et al., 1996). Experimental evidences indicate that at high salinity, mangroves spend more energy to maintain water balance and ion concentration rather than for primary production and growth (Clough, 1984). On the Pacific coast of Central America, freshwater availability (largely from rainfall and land runoff) controls reproductive phenology, growth and mortality of *Avicennia bicolor* (Jimenez, 1990). However, low salinity, associated with long periods of flooding, contributes to mangrove degradation through reduced cell turgidity and decreased respiration. Mangroves are poor competitors under non-saline areas where freshwater marsh plants easily out-class them. To cite an example, in Americas, the riverine mangrove forests disappeared at the Amazon and Orinoco river estuaries, where
freshwater flow dominated over the tidal prism and under this situation; freshwater macrophytes replaced mangroves (Lacerda et al., 2002).

Salinity at high levels also affects mangroves. For instance, high salinity reduces the biomass in hydroponically grown Bruguiera gymnorrhiza (Naidoo, 1990), and causes denaturing of terminal buds in Rhizophora mangle seedlings (Koch & Snedaker, 1997). Saline interstitial water is known to reduce the leaf area, increases the osmotic pressure leaf sap, increases the leaf area/weight ratio, and decreases the total N, K, and P minerals (Medina et al., 1995). Simple salinity fluctuations also have significant negative effects on the photosynthesis and growth of plants (Lin & Sternberg, 1993). In Senegal, hypersalinity (from a decade of low rainfall and high evaporation) has caused the growth of salt marshes invading into mangrove areas and thus completely destroying their vegetation (Diop et al., 1997). Extremely high salt concentrations in the groundwater of tropical salt flats are also responsible for the complete absence of mangroves in such locations. There are often very sharp changes in the groundwater salt concentrations at the interface between salt flats and mangroves indicating that the mangroves are modifying the salinity of the groundwater (Ridd & Sam, 1996). Mathematical models developed for the groundwater flow show that human activities at hundreds of kilometers inland can destroy vast areas of mangroves by changing the flow of groundwater and thus modifying the salinity levels (Tack & Polk, 1997).

**Rainfall and supply of freshwater**

The availability of freshwater is an important factor for the development and growth of mangrove forests. Freshwater supply has often been indicated by the ratio of rainfall to evapotranspiration. Under the humid conditions, where the ratio exceeds 1, the mangroves grow luxuriantly. In arid climates, on the other hand, where the ratio falls below 1, the mangroves get stunted. High rainfall in humid areas leaches out residual salts from the mangrove soil and thus encourages the growth of mangroves. For example, along the Panama coast and southern coast of Costa Rica, where the annual rainfall ranges between 2100 and 6400 mm, mangroves exceed 35 m in height and have a biomass of 280 t ha⁻¹ (Jimenez, 1992). In the arid regions, barren salt flats often develop along the landward rim of the mangroves, due to poor leaching of salts from the soil due to low rainfall and this result in poor growth of mangroves because of high salinity of the soil.
**Sediment characteristics**

Three conditions favour mangrove formations and these are:

1. Open seashores where substratum is muddy and also protected,
2. Protected banks of estuaries, and
3. Creeks which cut across the land mass. Among these three, protected banks of estuaries are the best suited locations for the mangroves.

One of the important factors in the mangrove habitat appears to be nutrient concentrations. Nutrient fluxes in these environments are closely dependent upon plant assimilation and microbial mineralisation (Alongi, 1996). Two major elements (N and P) are of great significance for the growth of mangroves. The concentration of dissolved inorganic nitrogen is generally low in tropical mangrove waters. Some microorganisms incorporate N\(_2\) from the atmosphere and convert the nitrogen present in the soil into ammonium, which makes nitrogen available for the use of plants. Ammonia is the main form of inorganic nitrogen in mangrove soil. It combines with oxygen to form nitrite or nitrate by the process of nitrification, which is used by the plants. This process normally occurs in the root zone that releases oxygen. Like nitrogen, the concentration of inorganic phosphorus is also generally low in mangrove waters. It is normally available as a soluble salt that can readily be assimilated by the plants. Phosphate is efficiently adsorbed by the fine sediments of muddy areas rather than the coarse-grained sediments. This is probably the reason for mangroves growing luxuriantly in muddy environments.

Nutrient availability may limit growth and production in many mangals. Pulses of high nutrient can create immediate and significant changes in the vegetation. For example, on the southeast coast of India, seedlings grow 5 times as high and produce 4 times as many leaves in the post-monsoon season as they do in the dry season. The reason is attributed to high nutrient concentrations and moderately low salinity during the late monsoon period (Kathiresan _et al._, 1996a).

The limitation in nutrients and trace metals varies with individual mangrove habitats. For example, potassium levels may be important in some regions. _Rhizophora apiculata_ seedlings do significantly better in plantation sites enriched with potassium (Kathiresan _et al._, 1994). In general, the growth of mangroves in
carbonate soils with low-nutrients gets limited in phosphorus – impoverished situations. This happens because whatever phosphorus may be present gets bound with calcium, and is effectively held within the sediments (Silva & Mozeto, 1997). In mesocosm and field experiments with Rhizophora mangle seedlings, phosphorus enrichment produced a nearly 7-fold increase in stem elongation rates and a 3-fold increase in the leaf area. Nitrogen addition produced no such response (Koch & Snedaker, 1997). Similarly, low phosphorus availability limits the growth of dwarf R. mangle in a Belizean mangal (Feller, 1995) and promotes the development of hard, long-lived leaves called sclerophylls. The sclerophylls are probably just an adaptation to conserve the nutrients in these oligotrophic habitats (Feller, 1996). Mangroves may develop other types of mechanisms to conserve valuable nutrients. For example, mature photosynthetically active leaves have much higher nitrogen and potassium concentrations than senescent leaves. This is apparently a result of nutrients being translocated from the ageing leaves and into other parts of the plant before the leaves fall (Soto, 1992).

Damage to mangroves declines the levels of nutrients. For example, severely damaged mangrove sites in North Queensland led to a significant loss of both nitrogen and phosphorus from the soil (Kaly et al., 1997). This may be indirectly related to decline in crab population as indicated by a dramatic decrease in the density of burrows. The effect of disturbance differs from habitat to habitat and largely depends on the characteristics of sediments and the flow regime of nutrients in each site. For example, Triwilaida & Intari (1990) found that there are significant differences in the nutrient concentration of soil between the degraded and healthy mangrove stands. Kathiresan (2002) recorded low levels of available nutrients, high salinity and low microbial load in degraded mangrove soil, as compared to those in the soil of luxuriant mangroves.

Mangrove soils are in general acidic in nature; especially in those areas which get flooded infrequently and are located in the upper areas of the intertidal zone. Soil becomes loose because of the presence of fine sediment and decaying organic matter. In such conditions, the soil becomes black in colour and emits foul smell of H₂S due to anaerobic microbial activity in the soil.

The occurrence of sulphides is a characteristic feature of mangrove sediments and it influences the distribution of mangroves. For example, in a neotropical Florida mangal, the zone dominated by Rhizophora mangle (with its numerous aerial prop roots) has moderately reducing soil with low sulphide levels. In contrast, the zone of
Avicennia germinans has strongly reducing soils with high sulphides (McKee, 1993). In general, high sulphide levels can damage, reduce growth and cause high mortality of mangroves (Youssef & Saenger, 1998). Sulphide is formed due to reduction of sulphate and it is generally slower in young forests as compared to the older forests because of the occurrence of high nutrient level and low sulphide toxicity (Alongi, 1996). Disturbance can increase the rate of sulphide reduction. Clearing of mangrove forests or simple formation of canopy gaps can change the physical and chemical characteristics of the underlying soil, leading to anaerobiosis and an increase in the sulphide activity in the sediment. Heavy organic input can also increase sulphide production and the H₂S accumulation usually can kill the mangroves if their pneumatophores get covered by silt and are unable to transport oxygen to the rhizospheres. Because of the presence of aerial roots, Rhizophora species have better chances of survival even in aged mangrove soil high in H₂S. They thus form natural successful competitors to the less-tolerant Avicennia species.

References


